Crowd Simulation Incorporating Agent Psychological Models, Roles and Communication

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Abstract

We describe a new architecture to integrate a psychological model into a crowd simulation system in order to obtain believable emergent behaviors. Our existing crowd simulation system (MACES) performs high level wayfinding to explore unknown environments and obtain a cognitive map for navigation purposes, in addition to dealing with low level motion within each room based on social forces. Communication and roles are added to achieve individualistic behaviors and a realistic way to spread information about the environment. To expand the range of realistic human behaviors, we use a system (PMFserv) that implements human behavior models from a range of ability, stress, emotion, decision theoretic and motivation sources. An architecture is proposed that combines and integrates MACES and PMFserv to add validated agent behaviors to crowd simulations.

Keywords

Crowd simulation, autonomous agents, human behavior models, culture and emotions

1. Introduction

There are many applications of computer animation and simulation where it is necessary to model virtual crowds of autonomous agents. Some of those applications include education, entertainment, training (for the military and police) and human factors analysis for building evacuation or other scenarios where masses of people gather such as sport events and concerts. Many producers and consumers of training simulator and game environments are beginning to envision a new era where psycho-socio-physio-logical models could be intertwined to enhance their environments' simulation of human agents.

Animating virtual crowds is often mediated by local rules [17], forces [11], or flows [3]. The next challenge in crowd animation is to simulate realistically how communication affects the behavior of autonomous agents and how having a psychological model for each agent can enhance the emergent behavior of the crowd [24,25].

Most crowd simulation systems are implemented by having a large number of individuals who have exactly the same behavior. Some systems offer a limited variety of behaviors by differentiating agents based on age and gender. Current crowd simulation systems lack a wide

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variety of behaviors based on demographically and culturally validated behaviors. In order to achieve this goal, we believe there is a need for a psychological model driving each agent's mind and therefore its decision making process.

When simulating human behavior, it is essential to model the psychology factors that affect their decisions. For example when simulating panic and time pressure during evacuation, it is important to model the following observations:

- Individuals may not be aware of the internal connectivity of the building and therefore may ignore some suitable paths for evacuation [23].
- Rising stress levels have the effect of diminishing the full functioning of one's senses, which leads to a general reduction of awareness, especially the ability to orient oneself quickly in rooms and surrounding areas [29].
- Agents that have not been properly trained are likely to feel stressed and might reach the point where they find themselves incapable of making the right decision due to time pressure [9]. On the other hand, trained individuals such as firefighters deal better with a dynamically changing environment and choose the best sequence of actions based on their perception and knowledge of the environment.

To take into account psychological elements that affect human behavior, we make use of PMFServ [24,25]. PMFserv was conceived as a software system that would expose a large library of well-established and data-grounded Performance Moderator Functions (PMFs) and Human Behavior Representations for use by cognitive architectures deployed in a variety of simulation environments. Its principal feature is a model of decision-making based on emotional subjective utility constrained by stress and physiology. PMFserv has become an agent architecture in its own right – with the flexibility to either act as a meta-level emotional arbitrator for other cognitive architectures or provide a fully functional stand-alone system to simulate human decision making.

The idea of using a psychological model is that agents will operate independently in perceiving the simulated world and in forming their reactions to it. At no point will they be pre-scripted or programmed via rules or procedures. We only model personal value weights on a need hierarchy as well as cultural standards, and individual agents will make their own (micro)decisions that lead to the emergent macro-behavior.

In this paper we present a framework that combines the PMFserv psychological model in our MACES crowd simulation system [19]. MACES deals not only with the local motion of individuals within a room but also with the wayfinding process that allows them to explore and learn the internal structure of a building. Therefore our agents can find their way around an environment that they were not familiar with in advance. Agents can also communicate among themselves to share information and manifest varying behaviors based on their different roles.

2. Related Work

There have been several cognitive agent architectures proposed to generate human-like behaviors. Brogan and Hodgins [2] used particle systems and dynamics for modeling the motion of groups with physics. Helbing [11] describes methods to simulate the movement of pedestrians based on a social force model which is a microscopic (personal) approach for simulating pedestrian motion. It solves Newton's equation for each individual and considers repulsive interactions, friction forces, dissipation and fluctuations. Tu and Terzopoulos

worked on behavioral animation for creating artificial life, where virtual agents are endowed with synthetic vision and perception of the environment [8]. Reynolds [21] first used a distributed behavioral model to produce flocking behavior.

Traditional crowd simulators ignore the differences between individuals and treat everyone as having the same simple behavior, but there are other models that represent each individual as being controlled by rules based on physical laws or behavioral models. In a multi-agent system, the agents are autonomous and typically heterogeneous. Research here is concerned with coordinating intelligent behaviors among a collection of autonomous agents so that they can coordinate their knowledge, goals, skills, and plans jointly to take action and to solve problems. Some applications include crowd behavioral models used in military training [30] and simulations to support architectural design both for everyday use [1][22] and for emergency evacuation conditions [26, 17].

Other models have been incorporated into commercial software tools such as regression [16], route-choice [12], queuing [14], gas-kinetic [10], and microscopic models. Of particular relevance to individualized actions, the microscopic models describe the time-space behavior of individual agents. There are two subcategories: the Social Force models and the Cellular Automata (CA) models. The difference between them is in the discretization of space and time. Social Force models [11] describe agent behavior microscopically by social fields induced by the social behavior of the individuals. In the Cellular Automata approach the study area is represented by a uniform grid of cells with local states depending on a set of rules which describe the behavior of the cell occupants [3,13]. These rules compute the state of a particular cell as a function of its previous state and the states of the adjacent cells.

In order to reduce the complexity of controlling all the agents in the crowd, while still maintaining detailed behaviors, several systems have attached information to the environment [7,28,27]. Our MACES system also embeds information in the environment, such as shortest paths. Individual agents will have differential types of access to that information and they will use it in different ways depending on their individual behavior at any given moment.

The PMFServ psychological model was not designed for a specific problem domain or level of detail, and as a result offers a high degree of flexibility of representation that allows it to be readily employed in many simulation domains. It has, however, been used to build physiological and psychological models of crowd members. Figure 1 shows a screen capture of a protest scene developed using PMFServ and Opensteer (http://opensteer.sourceforge.net/)

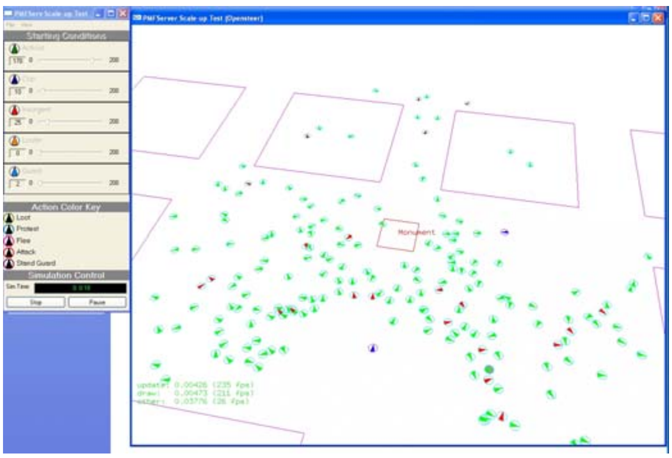

Figure 1: Screen capture of a protest scene developed in using PMFServ and Opensteer.

3. Architecture Overview

Presently we are designing and implementing an integrated architecture to generate realistic crowd simulation with a wide variety of individualistic behaviors. We first describe the MACES system [19] which implements and illustrates the agent bodies, actions and results when using communication and roles, and then the PMFserv system which provides the agent's motivations, stress, copying style, emotions, personality and decisions. Finally we will describe how we can integrate these two systems in order to enhance the emergent behavior of crowd simulation by applying psychosocial behavioral moderators to each of the individuals.

3.1. MACES: Multi-Agent Communication for Evacuation Simulation

MACES computes agent navigation at two levels. The high level corresponds to the wayfinding process of finding the sequence of rooms towards an exit, and the low level corresponds to the local movement within each room using social forces. For a given environment, the shortest paths from each room towards an exit will be saved within the environment. This information can represent either the known path that an individual would have followed when entering the building, or the path indicated by the emergency exits.

Each agent will have its own mental map which abstracts the geometry of the building and is represented by a cell and portal graph, where the nodes are the rooms and the arcs are the portals between rooms. Mental maps will be expanded as an agent explores the environment and shares information with other individuals of the crowd through the communication process.

The communication process occurs between individuals in a room. It involves information about location of hazards blocking possible paths and directions within a room that have been explored and where no exit was found. This localized sharing of mental models is the key to our algorithm's wayfinding behavior.

Different roles are applied to simulate a variety of behaviors. These roles depend on two attributes: leadership and training:

- Trained leaders have complete knowledge about the building's internal structure and would help others during the evacuation process. An example of this type of agent would be a firefighter.
- Untrained leaders correspond to people that by nature can handle stress better, tend to help others and will explore the building searching for new paths.
- Untrained non-leaders (followers) represent dependent people who might panic during an emergency situation and reach the point where they are incapable of making their own decisions.

The results obtained using MACES for crowd evacuation show significant improvements in evacuation rates when using communication, the different emergent behaviors obtained by applying roles to the individuals of the crowd, and the relevance of having trained people in the crowd during an emergency evacuation. From the experimental data, we have observed that only a relatively small percentage of trained (building plan knowledgeable) leaders yields evacuation rates comparable to the case in which everyone is trained.

As an example, Figure 2 shows the different emergent behaviors obtained when using a high percentage of leaders vs. low percentage. The image on the left shows the high percentage of leaders unfamiliar with the environment who tend to explore it looking for exits. As a result, we can observe small groups of people searching the space and sharing information which yields a faster evacuation time. The image on the right shows a small percentage of leaders and therefore a large number of followers. As a result, the emergent behavior consists of a few large groups of people wandering together, following others and unable to make their own decisions, yielding an overall longer evacuation time.

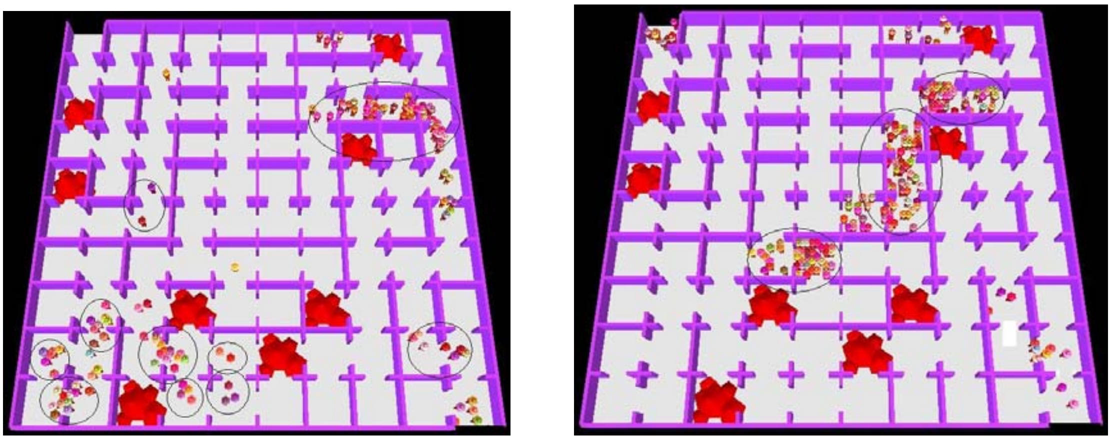

Figure 2: Example picture sequence of crowd evacuation with high vs. low percentage of leaders

3.1.1. High Level: Wayfinding

The high level component of MACES involves finding a path towards an exit. In order to achieve this, agents will perform different actions depending on their roles that will allow them to explore and learn the features of the environment. Figure 3 shows the three main steps of the high level algorithm.

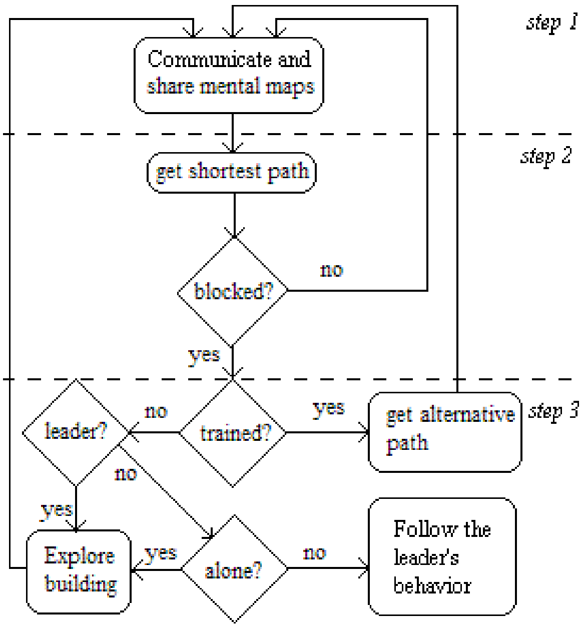

Figure 3: High Level Wayfinding diagram

The first step is the communication process. Agents within a room share information (symbolically) about the environment which consists of hazards found and directions to avoid because they have already been fully explored and no exit was found; e.g. "Do not go through door X, there is no exit", or "Fire found going north". With the information received, each agent updates its mental map of the environment. In the second step each agent checks its updated mental map to see whether the shortest path is blocked. Finally the third step consists of finding a new evacuation path when the known one is found to be blocked. Agents will proceed with different behaviors depending on their roles. Trained leaders with complete knowledge of the internal structure of the environment will just follow the next shortest path known. Untrained leaders need to explore the environment in order to find a new evacuation route. In order to achieve this, they perform an iterative depth first search. The last agent type are followers, which basically wait for others to make a decision and then they just follow them.

3.1.2. Low Level: Local Motion

The local motion within each room is based on Helbing's model [11] which describes human crowd behavior with a mixture of socio-psychological and physical forces:

Pedestrians $1 \le i \le N$ of mass m_i like to move with a certain desired speed v_i^0 in a certain direction e_i^0 and they tend to adapt their instantaneous velocity $\mathbf{v}_i$ within a certain time interval τ_i. At the same time, the individuals try to keep a distance from other individuals j and from the walls w using interaction forces $\mathbf{f}_{ij}$ and $\mathbf{f}_{iw}$. The change of velocity in time t is given by the acceleration equation:

$$m_i \frac{\mathrm{d}\mathbf{v}_i}{\mathrm{d}t} = m_i \frac{v_i^0(t)\mathbf{e}_i^0(t) - \mathbf{v}_i(t)}{\tau_i} + \sum_{j(\neq i)} \mathbf{f}_{ij} + \sum_{W} \mathbf{f}_{iW}$$

This model generates realistic phenomena such as arching in the portals [20] and the "faster is slower" effect. [6]. In our model (Figure 4) the desired velocity direction within each room is given by an attractor point that is located close to the next portal that the agent needs to cross. Therefore, each agent will walk towards the attractor while avoiding collision with walls and with other agents.

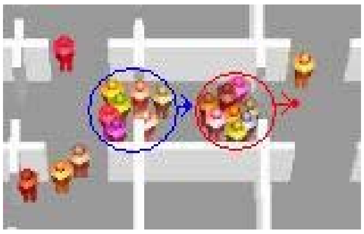

Figure 4: Arch formation and attraction points

3.2. PMFServ

Although the MACES emergent behaviors are significant, individual agents are limited to three distinct roles. For more realistic human behavior we need to expand the psychological representation. PMFserv ideally suits this role. PMFserv agents are built around a working memory data structure loosely corresponding to a short-term memory system. Modular PMF subsystems manipulate data contained both in the working memory and in a long-term

memory store. Information is layered on the working memory such that each layer is dependent on the layers below it for a given decision cycle of the agent (see Figure 5).

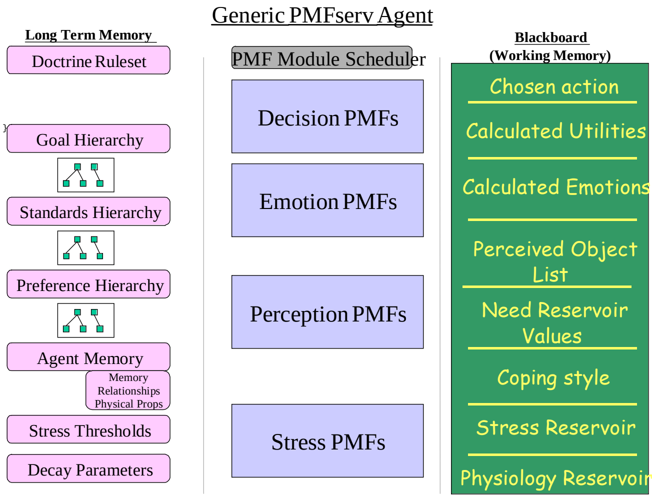

Figure 5: PMFserv Overview

Observing the working memory from the bottom up reveals the decision cycle of a single agent. Physiological data across a range of measures (including arousal, fatigue, hunger, thirst, injury, etc) are combined to set the levels of a series of stress reservoirs. The stress reservoirs then determine the agent's coping style (a measure of the agent's current awareness and capacity for rational thought) for the current decision cycle. Need reservoirs corresponding to the degree to which the agent has satisfied the needs outlined by Maslow [15] are set based on any action that might have occurred in between decision cycles.

Based on the agent's coping style, physiology, and any memory elements that might have been created prior to the current cycle, each object in the system executes its perception rules to determine which objects are currently perceivable by the agent and generates a list of how these perceptions affect the utility of actions in the environment. These perceptions of available actions are called affordances [4].

These affordances are represented in terms of the agent's emotion model. Our emotion model is based on the OCC model [18]. The general idea is that an agent possesses three hierarchical trees that describe the agent's Goals for Action, Standards for Behavior, and Preferences (GSR trees) for People, Objects, and Situations, respectively. An action can be represented by a series of successes and failures on the sub-nodes of these three trees. Each sub-goal is given a weight that describes how much it contributes to its parent node. To determine the emotional utility of an action, the OCC model multiplies the degree of success and failure of each node up the trees. From the top nodes on each tree, 11 pairs of oppositely valenced emotions are generated. By summing those emotions we arrive at a utility value for the action under consideration. This process is completed for every afforded action available to the agent. The action with the highest utility value is chosen and executed.

4. Interface between MACES and PMFserv

Our first major goal is to improve the MACES crowd simulation system by including a PMFserv psychological model that can affect the decision making process to achieve a richer variety of individualistic behaviors and more realistic emergent crowd behaviors. The

psychological model will affect not only the low level motion (i.e. modifying the speed of actions depending on the psychological state of the individual) but also the high level wayfinding (i.e. high levels of stress lead to loss of orientation).

MACES implements and illustrates the agent bodies, actions and results while PMFserv provides the agent's motivations, stress, coping style, emotions, personality and decisions. PMFserv implements the decision making processes while MACES manages the situated planning processes (wayfinding and local motion).

For each agent, PMFserv would operate its perception and run its cognition to determine collective and individual action decisions and pass instructions back to MACES to carry out the resulting actions and emergent behaviors. Figure 6 highlights the main interaction loop.

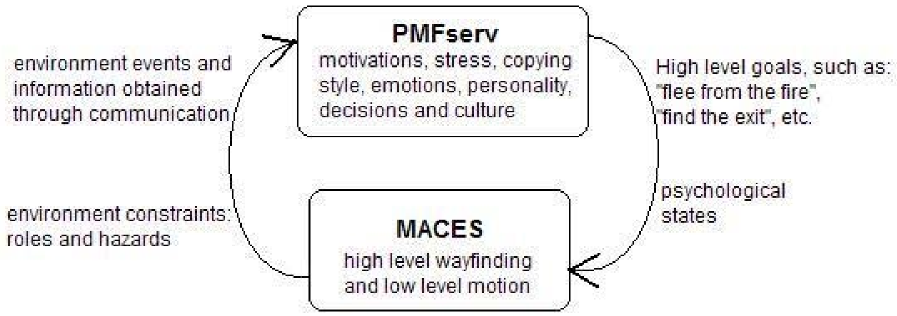

Figure 6: Main interface between MACES and PMFserv

MACES needs to have as an input the high level goals or actions that need to be performed such as "find the exit" and the emotional state of each agent. MACES will execute these actions based on current knowledge, the events perceived from the environment and its current emotional state. In PMFserv each agent is guided by the three value trees offering a goal hierarchy, standards (based on for example ethics, law, etc) and preferences.

MACES will provide information about the environment such as hazards that have been seen or information obtained though communication with other agents. PMFserv will then modify the GSP trees and therefore the emotional state of each agent. Table 1 shows a summary of the main modules and functionalities that each system offers.

PMFserv	**MACES**
- Event sensor - Psychology/Stress Module - Personality, Culture and Emotion Module - Decision Module - Response Selector - Semantic labeling of Events - World object Affordances	- Roles - Communication Module - Local motion (obstacle avoidance, herding, etc.) - Memory (mental maps) - Display services (2D and 3D, both real time) - Animation - Wayfinding Module

Table 1: Main modules and functionalities of each system.

MACES can interact with PMFserv via an API that allows the external simulator to change properties of objects in PMFserv and to generate events that an agent can perceive, resulting in responsive, reactive, and situated behaviors.

5. Conclusions

We have presented a framework to combine a psychological model (PMFserv) with a crowd simulation system (MACES). MACES offers: (a) a high level wayfinding algorithm to allow individuals in a crowd to explore an unfamiliar building in order to find exits during an emergency (b) inter-agent communication to share knowledge of the building during high level wayfinding, and (c) inclusion of certain roles to embed individualism in the crowd. PMFserv offers mature models for physiology, stress, perception and emotion. PMFserv can handle, e.g., the dysfunctional behavior that emerges in people during disasters, such as trance-like disbelief, milling, grouping and docile sheep-like following.

With the framework we presented, we are working towards developing a crowd simulation system able to achieve a wide variety of emergent behaviors based on validated human psychological factors.

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